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Methods of Testing the Dielectric Strength of Oils

Electrical Engineering

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METHODS OF TESTING
THE DIELECTRIC STRENGTH OF OILS

BY

FREDERICK JOHN FOERSTERLING

ALBAN WHITFORD MANN

THESIS

FOR THE

DEGREE OF BACHELOR OF SCIENCE

IN

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

Frederick John Foersterling and Alban Whitford Mann

ENTITLED Methods of Testing the Dielectric Strength of Oils

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Electrical Engineering

J M Bryant
Instructor in Charge

APPROVED: Ernst Berg

HEAD OF DEPARTMENT OF Electrical Engineering

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METHODS OF TESTING THE DIELECTRIC STRENGTH OF OILS

Introduction.

The dielectric strength of oil is an important factor in all high tension work. In the oil switch an oil with a high flash point and a very high burning point should be used. Neither should be less than 180° centigrade. The dielectric strength should also be high to prevent leakage between contacts or from contacts to ground. The oil should greatly resist the forming of an arc, quickly extinguishing it should it form. An arc in oil decomposes a portion, setting free a gas and carbon. The composition of the oil should be such that its dielectric strength will not be seriously and permanently affected by many electric discharges through it, caused by the repeated opening of the switch. The oil should be free from moisture, acid, alkali and sulphur. Moisture very seriously affects the dielectric strength, while the other impurities mentioned corrode the metal parts of the switch. It is very desirable to have the oil as fluid as possible and remain fluid at low temperatures and to have the color as light as it may be secured in an untreated oil.

In the transformer the function of the oil is twofold; first, it insulates the coils from each other and from the core; and, second, it conveys the heat away from the coils to the outer case or to cooling coils. The characteristics

required in good switch oils are also desirable in transformer oils. In transformer oils the viscosity should be as low as it is possible to obtain it to make circulation easy.

Although the dielectric strength of oil is very important, yet very little has been done toward standardizing the methods for its determination. This absence of a standard method to some extent accounts for the widely varying results obtained and the different conclusions formed by the various investigators. Steinmetz, Ryan, Tobey, Hendricks, Digby, and Mellis are among the foremost engineers who have investigated dielectrics. The results of their experiments with air are very consistent and agree closely. Their work with oils was carried on under entirely different conditions in each case; therefore, the results cannot be expected to agree. When comparisons are to be made in oil insulation data, the careful and comprehensive standardization of the American Institute of Electrical Engineers, made for tests in air, is missing.

The purpose of this thesis is to investigate the various methods of determining the dielectric strength of oils, in order that a standardization of methods may be affected.

Theory

The space surrounding charges of electricity is called an electric field. The intensity of this field is a function of the magnitude of the charge, of the radius of

curvature of the body, and of the distribution of the surrounding bodies. If two, point charges of electricity, q and q', are separated by a distance, r, the force of attraction or repulsion between the two is directly proportional to the product of the two charges and inversely proportional to the product of the square of the distance and a constant, C, where C is the specific inductive capacity of the dielectric. The difference of potential of any point in an electric field is defined as the work per unit charge which must be done on that charge to bring it from infinity to the given point.

If two equal point charges, A and B, are taken at a distance, r, apart and completely surrounded by a homogeneous dielectric, lines of force will leave these two points to form electric fields as shown in Plates I and II. Plate I represents the field when A and B are of unlike sign, and Plate II when the charges are of like sign. By referring to Plates I and II, it is seen that a plane passing through M and M' is a surface, all points of which are at the same potential. Such a surface is called an equipotential surface. Similiarly there are other equipotential surfaces represented in the figures by circles about A and B. These equipotential surfaces may now be considered to consist of thin conducting sheets and in no way alter the electric field.

The calculation of electric fields may be somewhat simplified by making use of the theory of images. Referring again to Plates I and II, the theory of images is simply, that B may be considered the image of A in MM' or vice versa. Then when dealing with the field, only one terminal and the

plane MM' need be used. The ratio of the number of lines of force which pass through a dielectric, to the number which pass through free ether under the same conditions is called the specific inductive capacity of the dielectric. From this it is seen that if a condenser has a capacity, C, when air is used for the dielectric, its capacity when any other dielectric is used is KC, where K is the specific inductive capacity of the dielectric.

Steinmetz (Transactions A. I. E. E., June 1, 1898) published the results of his experiments with the dielectric strength of air. He used spheres and needle points for terminals. The results secured were very consistent. The curves plotted from experimental data between effective kilovolts and length of air gap in inches tend to become straight lines at the larger gap distances and the higher voltages. This straight line portion of the curve begins at shorter gap distances with the smaller terminals, beginning with a two and one-half inch gap and forty kilovolts for needle point terminals, and with a five inch gap at seventyfive kilovolts with the one inch spheres. With a constant voltage the striking distance was always greatest for the smaller terminals. He also discovered that the insertion of an electrical conductor as a brass disc between the electrodes increased the striking voltage as much as twelve percent. The increase varied with the position of the conductor, it being greatest with the conductor midway between the terminals as shown in Plate III. Three conductors spaced equally between the terminals produce the same increase.

Tobey made tests on the dielectric strength of oils and was very careful to follow certain methods standardized by himself. He published the results of his experiments. (Transactions A. I. E. E., July 1, 1910). He found that the results were not affected by the introduction of resistance in series with the terminals and states that in his estimation the dielectric strength is not affected by being under continued stress. He also found that the results were not influenced by a variation of frequency within the commercial range, nor by an ordinary variation of temperature. The terminal shapes greatly affect the value of the breakdown voltage, those producing the greater concentration of electric stress giving the lower values for a given distance. Two discs as terminals give the highest voltage. This value is decreased by the use of spherical terminals and is again lessened by the substitution of needle points. It was found that the minimum striking voltage is secured with one disc and a needle as terminals. With a disc and a needle point as terminals, the distribution of Faraday tubes is somewhat as shown by the full lines in Plate IV. If the difference of potential be gradually raised, the dielectric will eventually be ruptured under a critical electric stress. If the plate be moved a little further away from the point and the same difference of potential used, the total number and density of Faraday tubes will be slightly diminished. To bring the density back to its original value the difference of potential must be increased. The density of this field is least in the immediate vicinity of the disc; therefore, the increase

in difference of potential required, expressed as a fraction of the original difference of potential will be less than the increase in distance, between the plate and point, expressed as a fraction of the original distance. From this it is to be expected that the curve, plotted with breakdown voltages as ordinates and distances between terminals as abscissae, will bend over as the distances increase. Actual tests proved this to be true.

If in the above arrangement of terminals the point is swung to the opposite side of the disc an exactly symmetrical distribution of the field is obtained here, as shown by the dotted lines in Plate IV. Therefore, if two points were used as shown, with double the difference of potential between them as between the disc and one point, the distribution of the field, as well as, the maximum intensity would be exactly the same. This would lead to the expectation that the puncturing voltage between two points would be twice that necessary to break down half the distance between a disc and a point. This was found by experiment to hold true, if the field is not affected by some external influence.

The dielectric strength of oil was found extremely sensitive to minute quantities of moisture. The effect of an increase in temperature was to slightly increase the dielectric strength and greatly decrease the insulation resistance.

Ryan in his work, "Air and Oil as Insulators", published (Transactions A. I. E. E., January 1, 1911), contends that the failure of oil as an insulator is due to ions set

free by the electric stress from the supply of free ions in the metals of the terminals and that to detach ions from a metal to a gas requires a greater stress than from the same metal to an oil. From these contentions he draws the conclusion that a compressed gas, with regard to insulating quality alone, must be superior to oil.

Among the foremost foreign engineers interested in the testing of oils are Messrs. Digby and Mellis. Their tests extended over a period of many months and their results were published in the June 1910 issue of the Journal of the Institute of Electrical Engineers. They mention the absence of standardization in testing, and prove that minute traces of foreign matter in an oil largely affect the insulation resistance, moisture being the most troublesome element. They advocate testing the dielectric strength of oil between a disc and a needle point, keeping the distance constant and raising the voltage gradually. They found curves plotted with kilovolts as ordinates and sparking distances as abscissae, for six different samples of oils to fall very near the parabola $y = 0.895\sqrt{x}$. Using a disc and one needle as terminals, they maintain, gives the lowest possible puncturing voltage over a given distance and, therefore, produces the conditions to be expected in actual practice. The results obtained are as consistent as gained with the use of two points as terminals. They also found the dielectric strength to increase with an increase in temperature, but, contrary to the American investigators, they found the specific resistance to increase at the same time. They very forcibly bring out the fact

that the dielectric strength of different drums of oil in the same consignment differ widely. The breaking of a 35 ampere, 440 volt circuit two hundred times within several samples of oil was found to lower their specific resistance and to increase their dielectric strength. Their explanation of this was that the repeated discharges carbonized the oil.

In the June 1, 1905, issue of the Transaction of the American Institute of Electrical Engineers is found a discourse on, "Methods of Measurement of High Electrical Pressures", by Kintner, in which he brings out the fact that anything which will change the charging current of the gap or of its mounting will affect the breakdown distance of a given voltage. A slight break in a gap circuit containing capacity was found to produce very erratic results, always calling for too large a gap for a given difference of potential. He recommends the use of terminal shields where no current limiting devices are in the circuit. Gaps with round nose terminals are subject to variations when grounded, the tendency being to require a higher voltage. With needle point terminals this effect does not present itself. The above effect in the round nose terminals may be eliminated by the use of shielded terminals, which, however, require a larger voltage for a given length of gap.

Apparatus

As a source of power in the experiments made by the

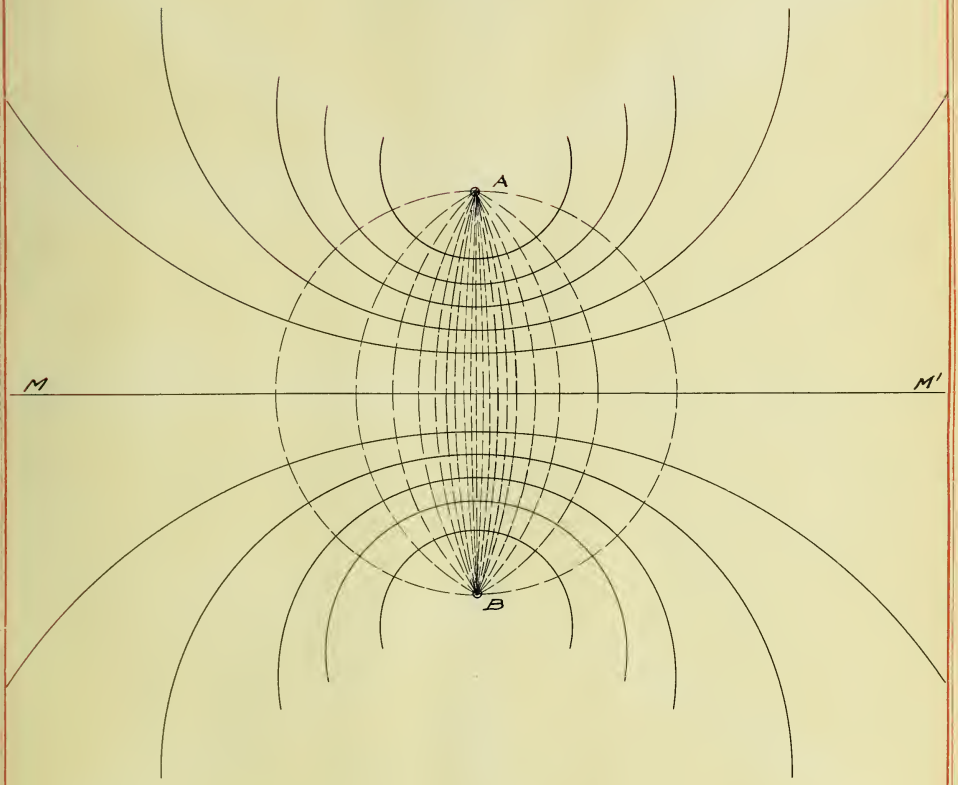
writers, a two phase Westinghouse alternator giving a normal terminal pressure of 440 volts, at 60 cycles was used. This alternator was of the revolving armature type and gave very nearly a sine wave of electromotive force.

The transformer from which the high tension voltage was obtained is shown at "A" on Plate VI. The primary of this transformer and a reactance coil were put in series, and connected to one phase of the alternator. The purpose of the reactance was twofold. In the first place, it eliminated a slight third harmonic present in the wave of the electromotive force, and, in the second place, it prevented a sudden and excessive rush of current when the system was on a temporary short circuit due to a breakdown of the oil under test. This transformer is capable of stepping up the voltage from 440 to 100,000 volts, and has a capacity of 10 KW. The high tension voltage was controlled by changing the pressure impressed on the primary of the transformer by means of a rheostat in the same room with the transformer, and connected in the field circuit of the alternator.

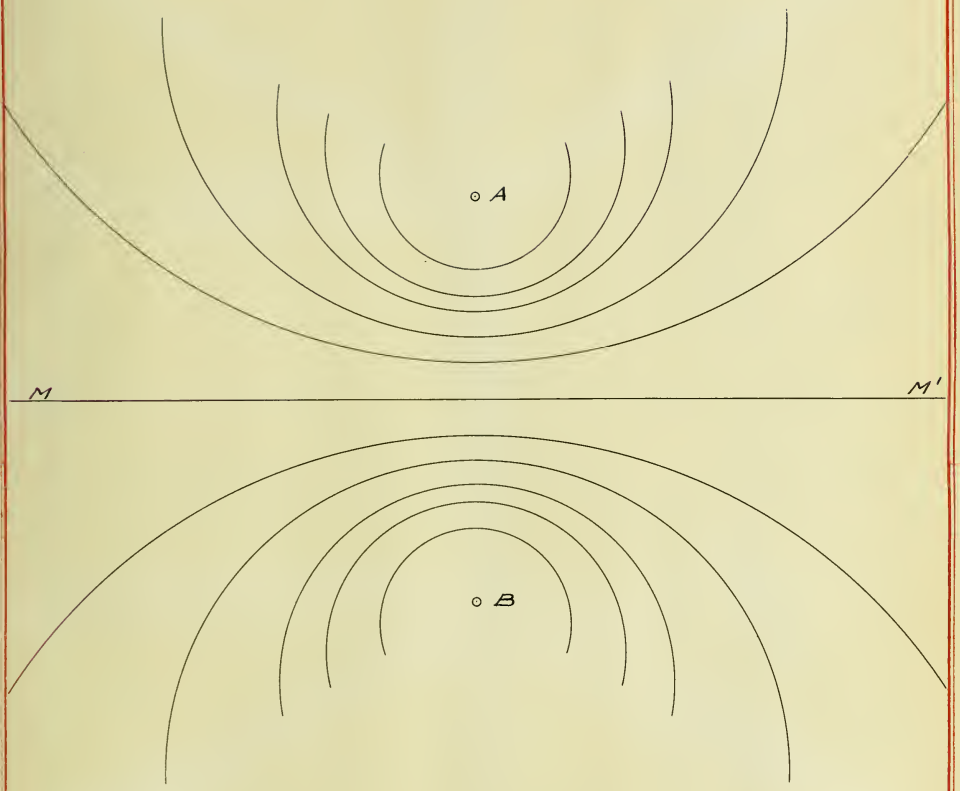
In determining the high tension voltage two instrument transformers shown at "B", Plate VI, were used. These stepped the voltage down in ratio of 300 to 1 which gave a voltage on the low side that could easily be read on a voltmeter of ordinary range.

The main piece of apparatus used in these tests is shown at "F" on Plate VII. This was made by Messrs Bergner and Putnam for use in their tests on oil in 1910. For a full description of this apparatus reference should be made to

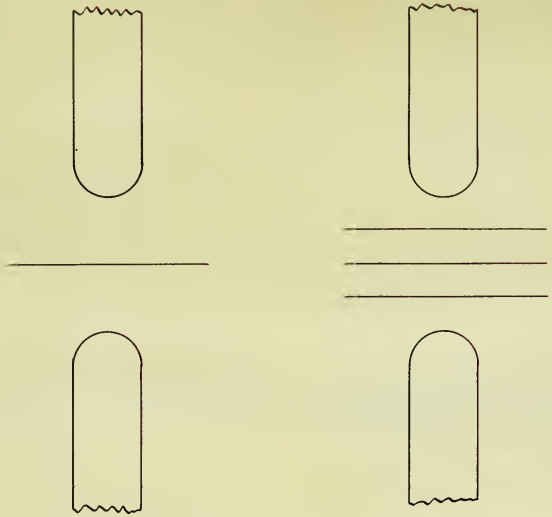
their thesis, "High Potential Tests of Oil", pp 2-4. The system of remote control of gap distance as described by these men was also used. The only changes made in these pieces of apparatus was the insertion of a spring under the micrometer to take up the back lash, and a smaller pulley on the controlling apparatus to give a more gradual adjustment of the gap. In order to determine the zero position of the micrometer, that is, when the terminals were just touching, a eight candle power lamp was put in series with the gap and across the lighting circuit. The terminals were then brought together until they touched, thus completing the circuit and lighting the lamp. The zero of the secondary dial on the micrometer was then moved to coincide with the zero on the main dial in order to keep this zero position.



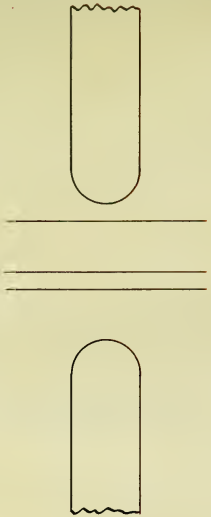
EQUIPOTENTIAL SURFACES
AND
DISTRIBUTION OF LINES OF FORCE
BETWEEN
TWO UNLIKE POINT CHARGES



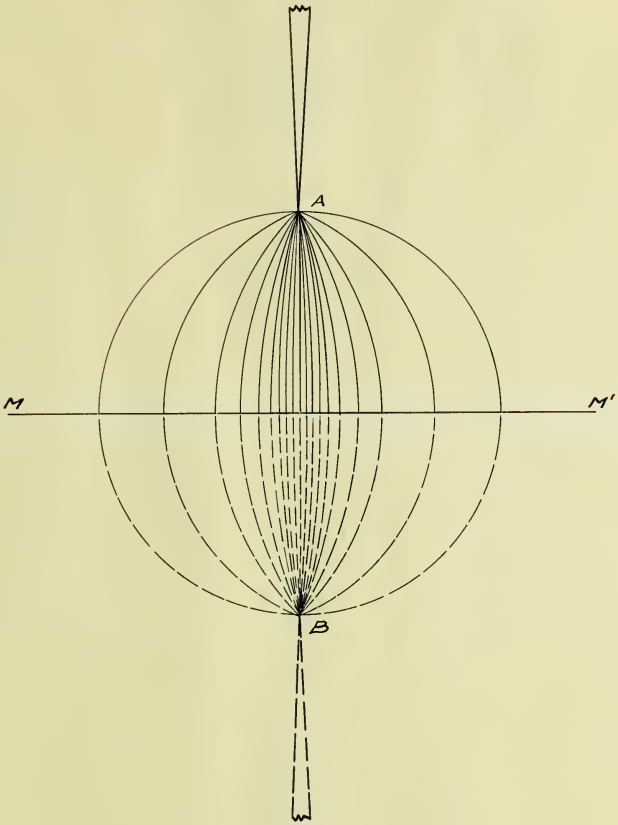
EQUIPOTENTIAL SURFACES
BETWEEN
TWO LIKE POINT CHARGES



Arrangements of Conductors between Electrodes Producing Maximum Increase in Breakdown Voltage with Distance Constant



An Arrangement of Conductors between Electrodes Producing less than Maximum Increase in Breakdown Voltage



DISTRIBUTION OF LINES OF FORCE
BETWEEN
POINT AND DISC ELECTRODES

Diagram of Connections

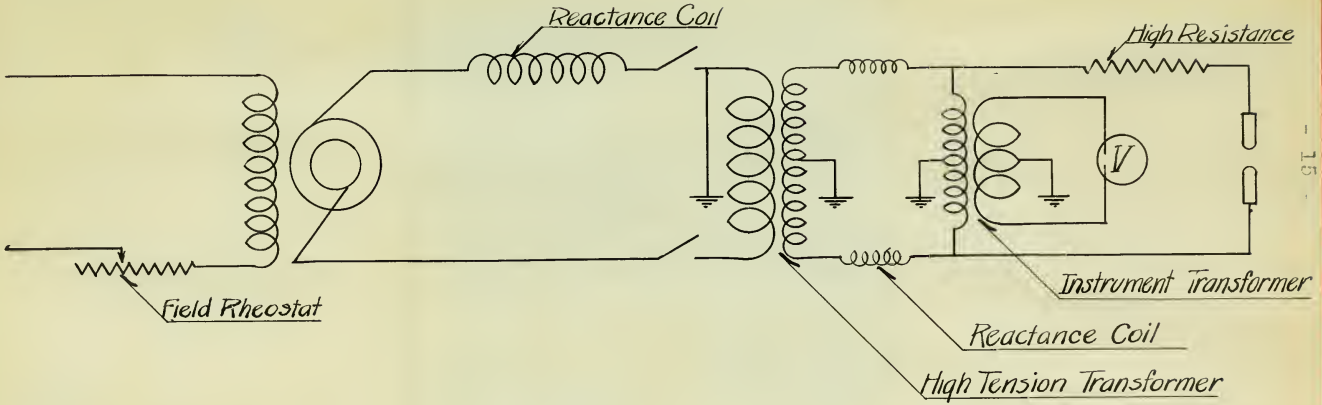
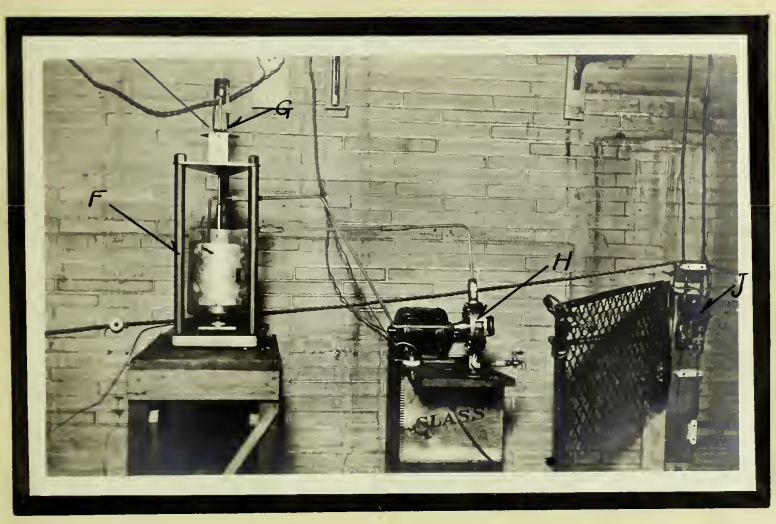
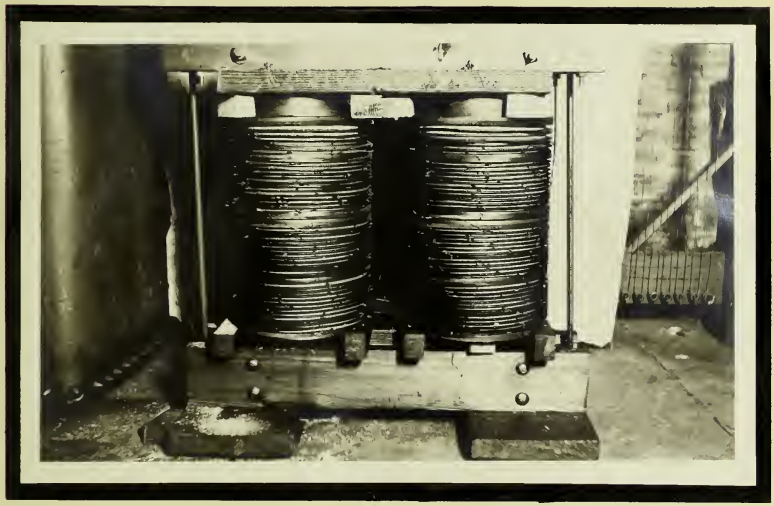


Plate V

A
B
C

Plate VII





Method of Testing

A great amount of trouble has been experienced by the various investigators in testing of oils for dielectric strength; the chief difficulty being in obtaining consistent results even on the same sample of oil.

The aim of the writers has been to find some method which would give uniform results on tests of oil over a wide range of voltage. In other words, to find the relation between voltage and the distance which that voltage would breakdown a given sample of oil, and to find some method which would always give a breakdown for the same oil at the same voltage and distance. In trying to find such a method a great many variables were encountered. Some of these variables were hard to control, and on this account, wherever it was possible, they were eliminated altogether.

The tests were first run by placing the terminals a certain distance apart, and raising the voltage until breakdown occurred. The results obtained by this method were not at all satisfactory. The voltage at which breakdown occurred, for a given distance, could be varied over a wide range, depending upon the speed with which the voltage was raised. In order to eliminate any time element entering in this way, the scheme of keeping the voltage constant and varying the distance was tried. This proved to be much more satisfactory than the former method and was followed throughout these tests.

By watching the oil between the terminals with a

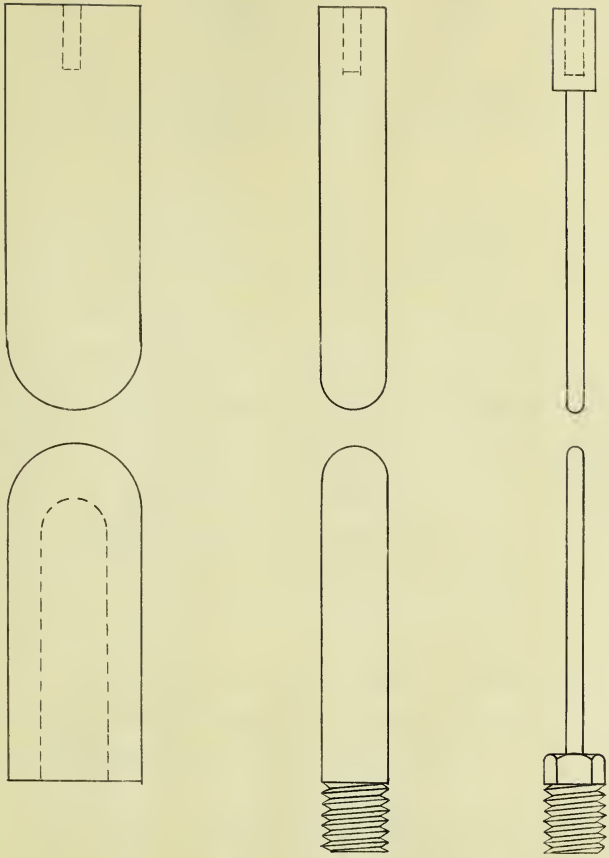
telescope while the voltage was applied, a perfect rain of small particles could be seen going from one terminal to the other. The powerful electrostatic field set up between the terminals tended to draw into it small particles held in suspension in the oil, such as water, and free carbon. After a number of these particles had been drawn into the path between the terminals, a conducting medium would be established and a discharge would take place. This process proceeded with different degrees of rapidity depending upon the amount of matter held in suspension, and the result was that the distance at breakdown for a given voltage would vary considerably. In order to prevent the electrostatic field from drawing in and holding such particles, it was decided to keep the oil circulating. For this purpose a small centrifugal pump run by a 1/20 H. P. motor (shown at H, Plate VII) was used.

Two method of circulation were tried, vertical and parallel to the electrodes, and horizontal. After taking various readings with each of the methods, the horizontal circulation, directly across the gap was found to give the best results. Curve number three shows the result of horizontal circulation to one side of terminals, and directly across the gap.

Various sizes of terminals were experimented with. All were of the general shape shown in the diagram, - cylindrical, having one end rounded off, the discharge taking place between the rounded ends of top and bottom terminals.

Fairly consistent results were obtained with all the

TERMINALS



terminals. The experiments did not proceed far enough to make it possible to determine just which of the terminals was the best.

Another arrangement used to aid in obtaining constant breakdown values was that of covering the outside of the jar which held the oil with tinfoil. This had the effect of making the electrostatic field about the terminals more uniform and thus making the oil subjected to a more uniform stress.

In all the tests which were made, kerosene was the oil used. The advantages of kerosene over other oils for test purposes are several. It is transparent and permits one to see what is taking place within it at all times, and the carbon which is formed by the discharges through it, settles out in a short time due to its low viscosity, thus allowing the same sample of oil to be used on successive days. Another important factor in determining upon the use of kerosene was its very low first cost in comparison with other oils.

In running the tests upon kerosene, the following method was finally determined upon as giving the most satisfactory and most nearly constant results.

First - The voltage across the gap was kept constant.

Second - Circulation of oil directly across the gap and then down.

Third - Terminals brought together by means of devices mentioned above until breakdown occurred.

Fourth - After breakdown, micrometer was read and terminals cleaned.

This process was repeated at each voltage for several readings. The average of these distances was taken as giving most nearly the correct distance at which that given sample of oil would breakdown under the pressure applied.

Discussion and Conclusions.

A considerable variation in the distance between the terminals for breakdown of the oil was encountered at any given voltage. Following are given some of the difficulties met with in this direction and also the method used in each case to eliminate the trouble as much as possible.

When an electric discharge takes place in oil, two things happen; the strength of the oil is increased and some of the oil is carbonized. Whether the small amount of carbon has anything to do with the increase of strength could not be determined in the limited time for test. It was shown, however, that repeated discharges in the same oil increased its strength up to a maximum point after which the strength decreased rapidly with the increase of carbon formed by these repeated discharges.

The effect of a few discharges upon the strength of oil is shown on curve sheet number four. The upper curve was taken using the same oil throughout, and the lower curve

using new oil at each different voltage. For a voltage of 30,000, the gap distance was .0895 inches in the oil which contained some carbon from previous discharges. With the new oil the gap distance for the same voltage was .111 inches, showing the new oil to have a less dielectric strength than the old.

When working at low voltages the oil is carbonized very slowly, and the same oil may be used for a number of readings. Upon reaching such values of pressure as 50,000 volts, one discharge will practically cause the given sample of oil to become carbonized to such an extent as to make it necessary to use new oil for the next test in order to have the readings check with previous ones. To prevent the oil from becoming carbonized an excessive amount by a single discharge, a resistance of 175,000 to 200,000 ohms, was put in series with the gap on the high tension side of the transformer. (See "C", Plate VI). This limited the current which would flow when the oil was broken down and consequently lessened the carbonizing of the oil.

Another variable encountered was due to the accumulation of carbon on the terminals after each discharge. To eliminate whatever effects this might have on the distance of breakdown, the terminals were cleaned of all carbon after each discharge, by rubbing with a piece of cloth.

The use of circulation brings in still another element which may cause results to vary considerably. This is the formation of air bubbles in the pump. When these bubbles are discharged into the jar they are drawn between the

terminals by the strong electrostatic field. The dielectric strength of air being less than that of oil, a premature discharge takes place while the terminals are much further apart than when oil alone is present. These air bubbles will cause the distance at which breakdown occurs to vary by such large amounts that it is useless to try to get an average value of breakdown distance when there is the slightest sign of them being given off by the pump.

Curve sheet number three shows how great an improvement is produced by circulation directly across the gap and cleaning terminals, over circulation to one side of gap or directly across it, when the terminals are not cleaned. For circulation to one side of gap as shown by curve number one, the distance at which the terminals were apart at breakdown varied over a wide range. This variation was reduced to some extent by circulation across the gap. Then by combining the circulation across the gap, and cleaning the terminals after each discharge, very nearly a constant breakdown value was obtained as shown by curve number three.

The results of using various sized terminals is shown on curve sheet number one. It is noticed that the general trend of these curves is toward the straight line. The smaller the terminal the sooner is the straight line portion of the curve reached. The curve for inch terminals is plotted for voltages up to and including 50,000, while that for one-half inch terminals is only plotted up to 40,000 volts, and that for one-eighth inch terminal only to 30,000 volts. The reason the curves were not extended higher is that above the

respective voltage which marks the maximum of each curve the results of successive discharges varied to such an extent that no attempt was made to definitely average the results. These results lead one to conclude that the cause of this variation was due to the very strong field at these points where the variation was so great. The smallest terminal produces the strongest field, and the voltage at which readings were stopped with this terminal was 30,000. With the one-half inch terminal very fair results could be obtained up to 40,000, but for a given voltage the field with the larger terminal is not so intense, and so it was to be expected a greater voltage would be necessary to show the same results as were obtained with the smaller terminal at 30,000 volts. When using still larger terminals - one inch - the point of variation was not reached until 50,000 volts. The results obtained for each size of terminal above these respective points with circulation varied similar to what they did at lower voltages without circulation. This leads one to believe that as the field becomes stronger it is enabled to hold the smaller particles which are drawn into it, even against the force of the circulation, thus rendering the circulation useless.

In taking readings on oil from day to day, while the results for each day were fairly constant at a given voltage, the results of different days for the same voltage, and same oil, would not agree at all. This necessitates taking all readings which are going to be compared with one another on the same day.

A curious fact noticed in making these various tests was the very consistent results obtained around 15,000 volts for successive breakdown of the kerosene. This held true no matter what size of terminal was used, and is shown on curve sheet number one, where the maximum and minimum curves are put in dotted lines. These curves come very close to the average value at about 15,000 volts on all the curves and then vary more and more from the mean as they go farther away from this value. Whether there was some connection between the dimensions of the various pieces of apparatus which were used could not be determined in the limited time for the tests, but all the results certainly point to some relation of this kind.

From these tests the following conclusions are derived:

First - Varying the gap distance at constant voltage gives more accurate and uniform results than varying the voltage across a fixed gap.

Second - Circulation of the oil and keeping electrodes free from carbon still further aids in obtaining uniform results.

Third - The dielectric strength of oil is very greatly affected by the number of discharges through it, especially at high voltages.

Fourth - The striking distance in oil at any given voltage up to 75.000 (the limit in these tests) is a constant value for any given size of terminals.

Fifth - When using kerosene, new oil must be taken for every different voltage in order to eliminate the error caused by carbon in the old oil formed by the discharges at the previous voltage.

Data for Curve Number One.

1" Terminals			1/2" Terminals			1/8" Terminals		
Sample No.	E	Dist. in Inches	Sample No.	E	Dist. in Inches.	Sample No.	E	Dist. in Inches
1	12000	0.0685	1	12000	0.0935	1	12000	0.1377
		0.0565			0.0700			0.1427
		0.0587			0.0655			0.1304
		0.0603			0.0750		Aver.	0.1369
	Average	0.0610			0.0970	1	18000	0.1708
2	18000	0.0734			0.0738			0.1830
		0.0720			0.0860			0.1796
		0.0736		Aver.	0.0801			0.1842
		0.0715	1	18000	0.0910			0.1940
		0.0719			0.0863		Aver.	0.1823
	Average	0.0720			0.0925	2	30000	0.2886
2	30000	0.1310			0.0940			0.2776
		0.1236			0.0912			0.2700
		0.1330		Aver.	0.0900			0.2885
		0.1303	2	30000	0.1610		Aver.	0.2810
		0.1420			0.1730			
	Average	0.1319			0.1706			
2	40000	0.1715			0.1516			
		0.1410			0.1500			
		0.1620		Aver.	0.1610			
	Average	0.1580	3	40000	0.2360			

Continued.

Data for Curve Number One (Continued)

1" Terminals			1/2" Terminals			1/8" Terminals.		
Sample No.	E	Dist. in Inches	Sample No.	E	Dist. in Inches	Sample No.	E	Dist. in Inches
3	50000	0.1934			0.2260			
		0.1584			0.2240			
		0.1656		Average	0.2290			
	Average	0.1724						

Note. - Date, April 19, 1911.
Weather rainy.
No inductance in primary. High Resistance in Secondary. 6" Glass jar. Readings taken after first discharge. Circulation across gap. Terminals cleaned after each discharge.

Data for Curve Number Two

1" Terminals			1/2" Terminals			1/8" Terminals		
Sample No.	E	Dist. in Inches	Sample No.	E	Dist. in Inches	Sample No.	E	Dist. in Inches
1	9000	0.0238	1	25000	0.0668	3	45000	0.1950
		0.0237			0.0680			0.1970
		0.0174			0.0752			0.1820
		0.0174			0.0712			0.1770
		0.0209			0.0720		Aver.	0.1880
		0.0209		Aver.	0.0704	4	50000	0.2229
		0.0196	2	30000	0.0805			0.2314
		0.0192			0.0790			0.2260
	Aver.	0.0203			0.0808		Aver.	0.2270
1	15000	0.0388			0.0836	5	60000	0.3325
		0.0300			0.0826			0.3315
		0.0410		Aver.	0.0813			0.3330
		0.0407	2	35000	0.1004		Aver.	0.3323
		0.0404			0.1005	6	70000	0.4250
		0.0467			0.0996			0.4240
		0.0438			0.1008			0.4290
	Aver.	0.0402			0.1010		Aver.	0.4260
	20000	0.0587		Aver	0.1004			
		0.0622	3	40000	0.1353			
		0.0622			0.1353			
		0.0604			0.1344			
		0.0548			0.1397			
		0.0665		Aver	0.1364			
	Aver.	0.0605						

Note - Date April 8, 1911. Weather - Cool and Cloudy. Reactance in primary. High resistance in secondary. 1/2" electrodes. Circulation across gap. Outside of 6" jar covered with tinfoil.

Data for Curve Number Three.

Circulation Jet to One Side Horizontal. Terminals not cleaned after each Discharge.

Sample No.	Dist in Inches.
1	0.0200
	0.0173
	0.0150
	0.0187
	0.0210
	0.0251
	0.0163
	0.0137
	0.0270
Average	0.0194

Circulation jet across gap. Terminals not Cleaned after Each Discharge.

Sample No.	Dist. in Inches.
2	0.0114
	0.0142
	0.0142
	0.0189
	0.0207
	0.0192
	0.0081
	0.0181

Circulation Jet Across Gap. Terminals cleaned after each Discharge.

Sample No.	Dist in Inches.
3	0.0103
	0.0097
	0.0104
	0.0112
	0.0112
	0.0114
	0.0124
	0.0111
	0.0123
	0.0106
	0.0115
	0.0118
	0.0124
	0.0104
	0.0120
	0.0108
	0.0108
	0.0097
	0.0124
	0.0126
	0.0122
	0.0124

Data for Curve Number Three (Continued)

Circulation jet across Gap. Terminals not Cleaned after Each Discharge.

Sample No.	Dist. in Inches.
	0.0142
	0.0182
	0.0174
Average	0.0157

Circulation Jet Across Gap. Terminals cleaned after each Discharge.

Sample No.	Dist. in Inches.
	0.0124
	0.0121
	0.0122
	0.0117
	0.0112
	0.0128
Average	0.0116

Note - Date, March 4, 1911.

E = 10,000 Constant

1/8" Terminals.

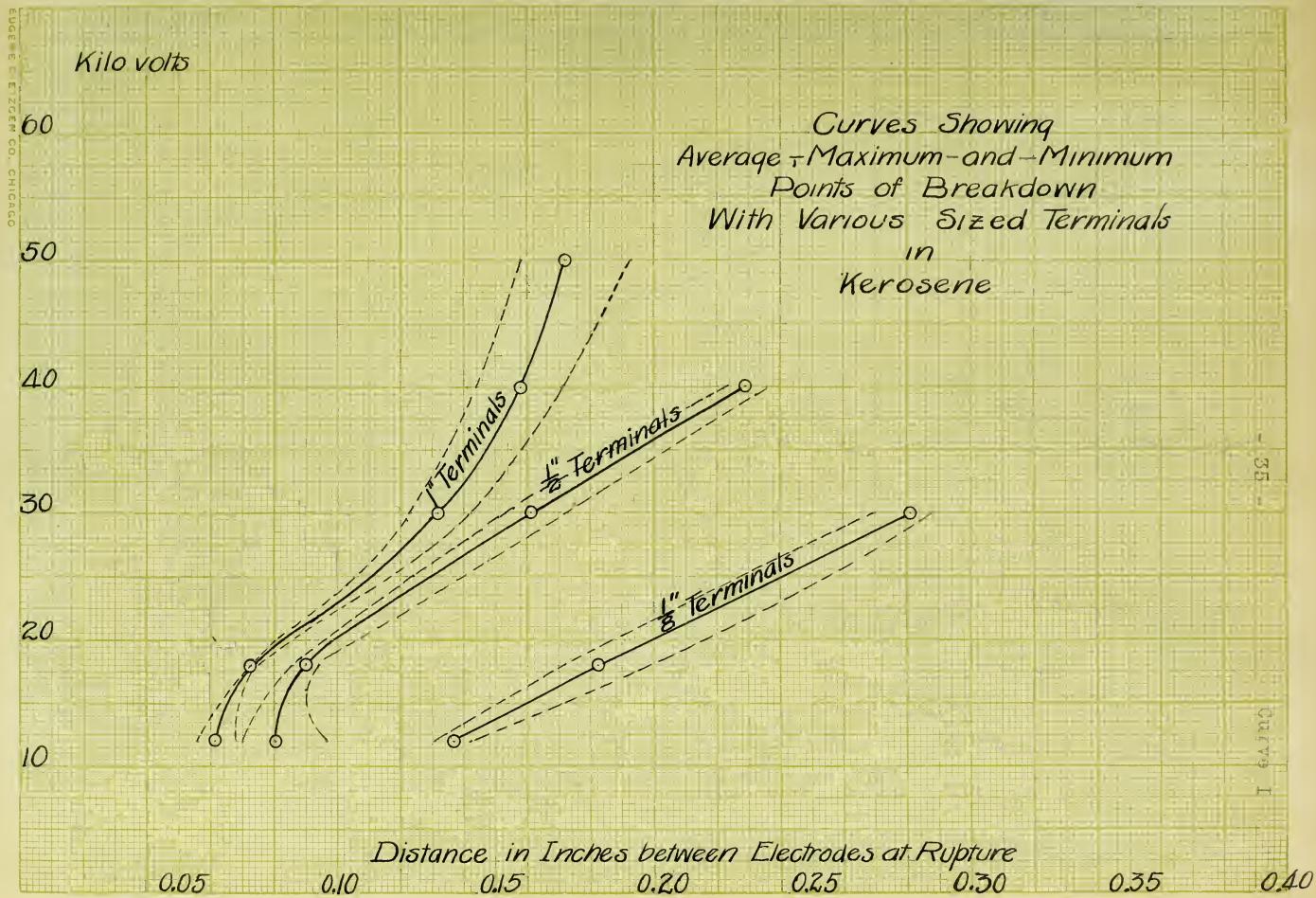
Reactance in Primary.

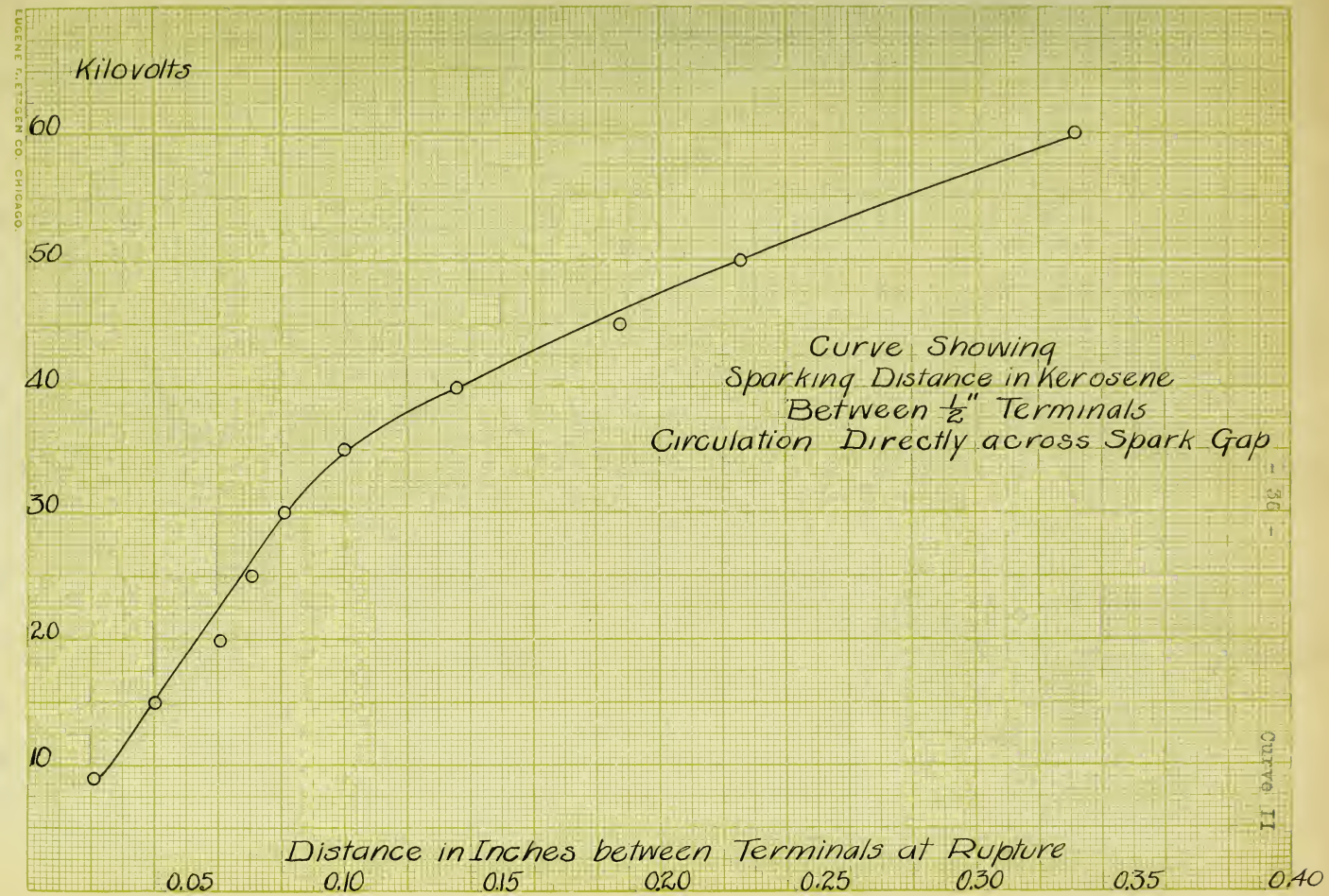
6" Jar.

Data for Curve Number Four.

Sample No.	E	Dist. in Inches	Sample No.	E	Dist. in Inches	Sample No.	E	Dist. in Inches
1	9000	0.0446	2	20000	0.0627	3	35000	0.1365
		0.0377			0.0660			0.1365
		0.0378			0.0661			0.1360
		0.0370			0.0628			0.1365
		0.0402			0.0685			0.1420
		0.0380	Average		0.0652			0.1230
		0.0343	2	25000	0.0777		Average	0.1350
		0.0330			0.0773	3	40000	0.1371
		0.0338			0.0675			0.1645
		0.0405			0.0737			0.1340
		0.0342			0.0690		Average	0.1452
	Average	0.0374			0.0745	4	40000	0.1558
1	15000	0.0500			0.0690			0.1580
		0.0500			0.0771			0.1520
		0.0491		Average	0.0732			0.1610
		0.0497	2	30000	0.0897			0.1613
		0.0510			0.0865		Average	0.1576
	Average	0.0500			0.0914			
1	20000	0.0670			0.0860			
		0.0647			0.0950			
		0.0620			0.0860			
		0.0569			0.0930			
		0.0572		Average	0.0897			
		0.0534						
	Average	0.0602						

Note - Date April 10, 1911. Weather Clear, Cool. Inductance in Primary. High Resistance in Secondary. Circulation across gap 1". Terminals cleaned after each discharge.


Kilo volts
60
50
40
30
20
10
Curves Showing
Average - Maximum - and - Minimum
Points of Breakdown
With Various Sized Terminals
in
Kerosene
1" Terminals
½" Terminals
⅛" Terminals
Distance in Inches between Electrodes at Rupture
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
- 35 -
Curve 1
EUGENE C. EITZEN CO. CHICAGO


Kilovolts
60
50
40
30
20
10
Curve Showing
Sparking Distance in Kerosene
Between ½" Terminals
Circulation Directly across Spark Gap
Distance in Inches between Terminals at Rupture
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
Curve 11
- 36 -
EUGENE DIETZGEN CO. CHICAGO.

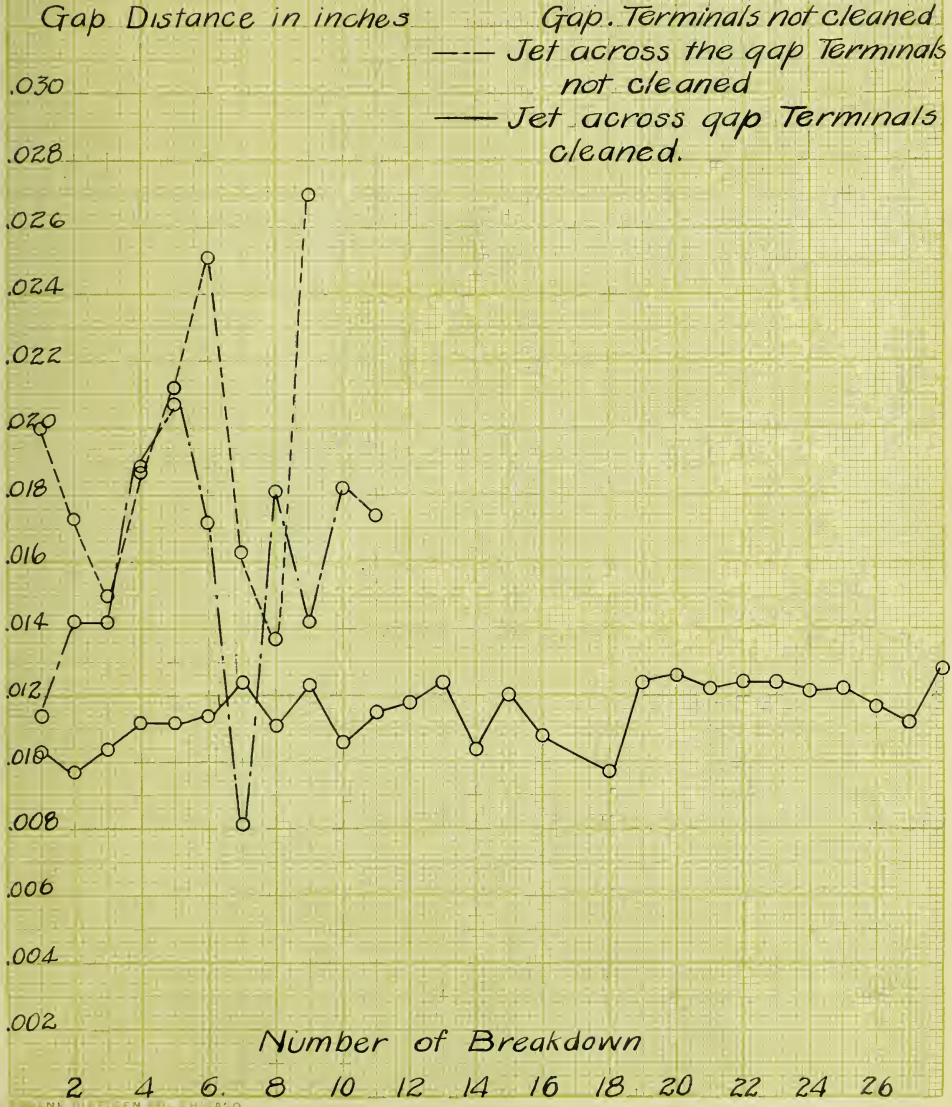
Curve III

Curves with 1/8" Terminals
Showing Effect of
Circulation Directly across Gap
and
Cleaning of Terminals

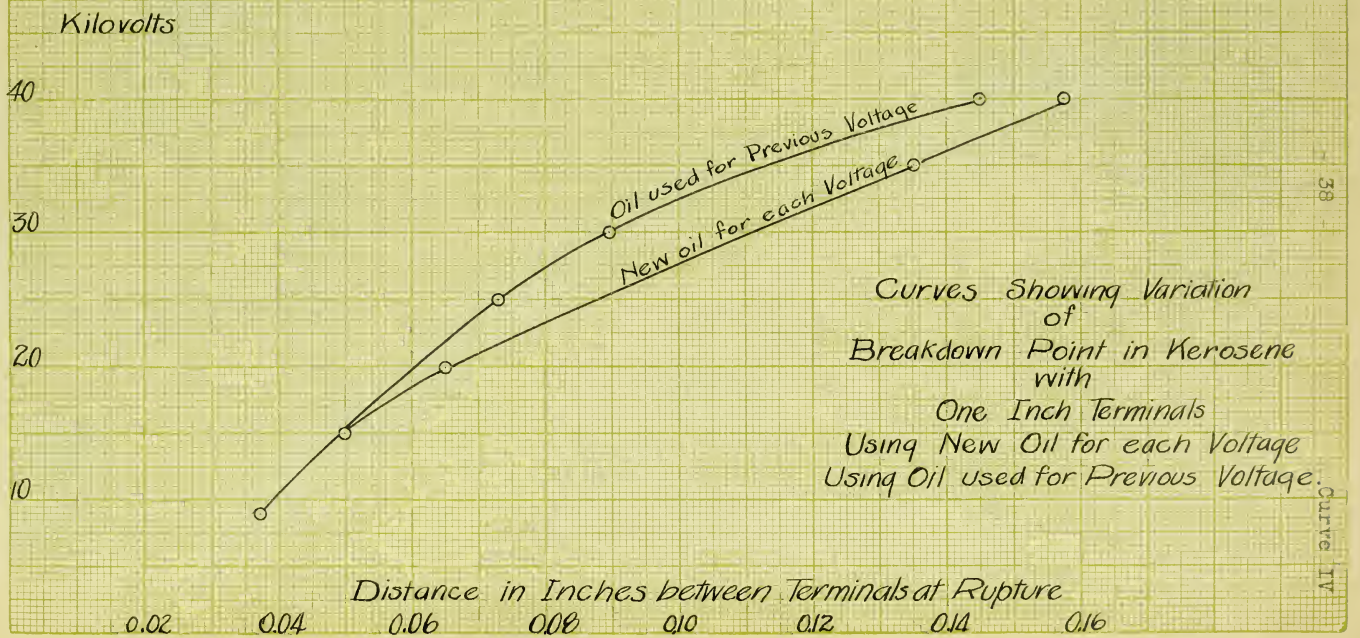
---- Horizontal jet to one side of Gap. Terminals not cleaned

—·— Jet across the gap Terminals not cleaned

—— Jet across gap Terminals cleaned.



EUGENE DIETZGEN CO., CHICAGO.



Curves Showing Variation
of
Breakdown Point in Kerosene
with
One Inch Terminals
Using New Oil for each Voltage
Using Oil used for Previous Voltage.

Curve IV

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